



Digital Twin Technology In Indian Healthcare : Exploring Opportunities And Challenges

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Abstract. Digitalization in the healthcare sector has been endowed with the Digital Twin (DT) Technologies. Seamless integration of data comprised of hardware, data management middleware, and software for monitoring, and integration from different digital platforms through interoperability, and to replicate those for creating the virtual model is known as DT. The significance underlies its precision and accuracy in customizing diagnosis, personalized patient-centric care treatment plan, analyzing workflows, medication, resource allocation, and enhancing patient safety. The potential benefits of DT are in proactive intervention in detecting health risks, including the variables in the genes, environment, and lifestyle of the patient, for clinical practice. India's healthcare sector is recognized as one of the cost-efficient countries in the Asia-Pacific region; hence, the significance underlies India's progressive journey towards indigenous innovative digital healthcare solutions. The National Health Policy (NHP) expanded its focus on accessibility, availability, and affordability of uniform and quality healthcare services, though only to a limited extent. Since the study concerns emerging exploratory fields, an analytical method is applied. To substantiate the analytical value, the operational extent of digital healthcare solutions, including the meta-analysis of the application of DT in India, if any, is also included in the study. The objective of the present study is to review, compare, and critically analyze NHPs, regulatory frameworks, and the suitability of DT within existing infrastructural frameworks. The study shall provide practical insights to policymakers on improving the institutional framework and regulatory mechanisms, as well as the operational feasibility and economic viability of DT in the Indian healthcare sector.

Keywords: Digital-Advancement, Economic-Viability, Healthcare, Legal-Framework, Patient-Centric Care.

1 Ideological Foundation Of Digital Twin

Seamless integration of data through computational technologies comprising hardware, data management middleware, and software for monitoring, and integration from different digital platforms through interoperability, and to replicate those for creating the virtual model is known as Digital Twin (DT). One of the biggest transformational opportunities of this century. The potential of DT lies in creating prototype predictive models to speculate on the behavioural patterns of complex structural networks of biological chemical substances, the progression of viruses or bacteria, and their attainable mutation capacities. From an economic standpoint, creating virtual prototypes saves on the cost of expensive physical models while being time-efficient. The experimental efficiency of the DT, for example, in healthcare services, combines the functionalities of tangible biochemical systems that subsist in living organisms (*in vivo*) with those in the test tube of a clinical laboratory (*in vitro*) using advanced computational and information technologies. This process is called the *silico* method. For the seamless operationalization (analyze, structure, reveal complex integration, and identify the patterns, trends, associations, interactions, etc. relating to behaviours of viruses, bacteria, and their behavioural interactions in human organisms, and eventually to create a virtual prototype model) of this method, collections of large and diverse data are the key element. In addition, the associated elements are continually advanced versions (i.e., automated AI-driven edge computational processing for integration and virtual simulation) of the Internet of Things (IoT), cloud computing services (also called digital thread), virtual reality (VR), augmented reality (AR), robust high-speed internet connectivity, and smooth interoperability in its associated digital platforms. In every level of its interactive pathway it provides paradigm accountability and analysis of investigated substances, through the associated interdisciplinary operations, it furnishes its projections, including complex physiological processes relating to its analyzing citation networks which in turn, enlarges valuable opportunities of future explorative research in realizing the chemical properties of compounds in human organisms, unravel the hidden patterns of multiple dimensions of molecular descriptors of importance (including undetected molecular descriptor), designing the healing techniques for the healthcare services. It provides opportunities to re-evaluate other ingredients present in healing techniques, e.g., food and cosmetic ingredients, environmental agents, etc., as well as for simulation, analysis, and optimization of the physical counterparts. The exceptional capacity of the DT is that it enables opportunities to interact effectively between two environments, i.e., the physical vis-à-vis the virtual, to address the challenging physical conditions [1]. This predictive validation proficiency of the DT saves valuable time and trial-based risks in healthcare services.

The multidimensional approaches of the DT offer immense functional benefits in providing valuable insights related to patient-centric healthcare services (e.g., in pharmacological, surgical, therapeutic, toxicological, physiochemical, biological, and so

on), hazard identification, risk assessment, decision-making process, and safety evaluation of human health at low cost [2].

1.1 Digital Twin in Healthcare Space

The advanced digital healthcare service model comprised four primary technological stages: (a) silent design; (b) overt, (c) data-enabled, and (d) convergent [3]. Between 1960 and 2010, the first stage of the silent procedure in the healthcare space, with no formal, professional discipline for the specific processual design of utilizing health data, was in practice. With increasing attention to structure and organization, using metrics for information related to the health anecdote for general practice, the design activities were formalized in the UK [4]. Thus, at the outset, it was an informal, unstructured inquiry to examine the accuracy of possible approaches in the healthcare system. Next appeared the overt design process, where data collection is carried out in a more formal and structured manner for future reliability. The professional-scientific framework for designing data collection by L. Bruce Archer introduced a substantive, progressive, entrepreneurial model in the healthcare landscape [5]. Thus, both silent (unstructured and unorganized systems of data collection) and overt (more professional and structured systems) designs are used simultaneously in healthcare services.

The emergence of innovative advanced digital technologies, especially post-2010, introduced two additional features in such a structured designing model, and they are: (i) analyze the data in real-time settings and perform based on digital data, and (ii) subsequent change and evolution in future utilization. These two factors have been characterized as data homogenization (i.e., conversion of all digital data into binary numbers) and reprogrammability (i.e., performance through digital devices across a wider range of flexible data infrastructure) [6]. These specificities in the domain of digital data management influenced the design loop to collect data from non-health sectors for creative use and the development of intelligent ecosystems [7]. This data-enabled design enabled the development of data infrastructure – the steady flow of persistent data and application of this design model in the healthcare domain facilitated the introduction of an intelligent ecosystem and provided correlated healthcare services. The commercialization of this data-enabled design is promoted to ensure a market for medical devices, e.g., BLE-enabled glucose monitors, smart watches, BP, ECG, heart rate, and blood sugar level monitoring devices, and other wearable sensor-embedded medical devices. Lastly, this incremental utilization of data through integration has developed the advanced approach called the convergence approach that introduced a new layer of complex, mutual, and interdisciplinary data designing processes for the delivery of new offshoots of healthcare services, e.g., clinical evaluation, cost evaluation, healthcare service management, policy making, algorithmic auditing, and so on. All data design approaches support the decision-making process. Still, the convergence approach offers greater precision, accuracy, and an individual-centric decision-making process – an emerging approach in digital healthcare solutions, and the DT falls under this purview. The data infrastructure

and automated edge computing have enabled cloud computing services to enhance the iterative cycles of exploration, monitoring, and detection of potential consequences in innovative healthcare services with precision and accuracy.

2 Presence Of Digital Twin In Healthcare Sector

DT has enabled the development of a simulated world in which the integration of in vivo and in vitro data, including locations and processes, is available. The seamless flow of information through digital infrastructure, with its associated instrumental digital artefacts, could enable swift, accurate, and individualized outcome prediction and condition-specific care services. In personalized medicine, or precision medicine (which avoids a one-size-fits-all approach and considers a patient's genes, environment, and lifestyle when developing treatment and disease prevention strategies), digital twins could be a revolution by creating virtual copies of each patient. Predict and diagnose the best possible treatment, healthcare professionals could use a patient's digital twin (DT) with tools such as machine learning and artificial intelligence.

There are various uses of DT. On a broader scale, DT can be used in healthcare centers to optimize the identification of problems and address various challenges, such as increasing patient demand, clinical complexity, limited space, and infrastructure constraints. DT settings in healthcare would mitigate various challenges and aid in preparing for and managing crises [8]. The significance of DT in the healthcare sector lies in its precision and accuracy in tailoring diagnoses, medications, and treatments. The unique characteristics of DT are proactive intervention in detecting health risks, including variables related to the patient's genes, environment, and lifestyle, for clinical practice, rather than the creation of computational physiology. The simulation models of DT enhance the optimization of health care management systems, e.g., photo-metric diagnosis, and help medical professionals comply with complex procedures for diagnosis, disease progression, pre-hospital and operative phase management by care service providers, insurance, and so on. The DT thus offers personalized, patient-centric care and treatment plans, analyzing workflows, resource allocation, and enhancing patient safety.

3 Global Outlook of Digital Twin Technology in Healthcare Sector

In the global healthcare market, the estimated growth of DT is from \$1.9 billion in 2024 to \$33.4 billion by 2035. About 90% of healthcare executives view digital twins as an essential technological development that enables collaboration among multiple systemic units within their organizations. Furthermore, the increasing demand for virtual simulation, precision medicine, and predictive maintenance is expected to drive deeper exploration of digital twin usage, especially in the pharmaceutical industry. A shift towards digital twins in healthcare facilities aims to deliver personalized care. The majority of DT companies use artificial intelligence in providing solutions. In the global

market, the Asia-Pacific region is projected to grow faster, at a CAGR of 45.9%, led by countries such as South Korea, Japan, India, and China.

Over USD 6.5 billion in the last four years, across the globe, various investors have invested in DT technology engaged in the healthcare market. The global digital twin market in healthcare is estimated to be worth USD 1.9 billion in 2024. The market is expected to grow at a CAGR of 30% over the forecast period, driven by the increasing adoption of digital health technologies. Further, in terms of application areas, digital twins intended for asset/process management currently capture the majority (32%) of the market share. However, in 2035, digital twins intended for personalized treatment are anticipated to capture the majority (29%) of the market share. A few notable recent advancements in digital transformation (DT) within the healthcare sector include: In December 2023, Twin Health, a US-based company, secured USD 50 million in a venture series funding round from Temasek, ICONIQ Growth, Sofina, and Peak XV Partners; these investors plan to utilize this funding to broaden the commercial application of its digital twin technology. Additionally, in December 2023, Quantum Genomics seeks to develop a personalized simulation digital twin tailored for healthcare providers and pharmaceutical companies [9].

India's healthcare sector has already been recognized as one of the cost-efficient countries in Asia and the Pacific. The progressive move towards digitalization in the Indian healthcare sector, pursuant to the National Health Policy, has extended the reach of accessibility, availability, and affordability of uniform-quality healthcare services, though to a certain extent. The objective of the present study is to review, compare, and critically analyse the health policies, regulatory frameworks, and the digital infrastructure of various jurisdictions.

4 Legal Implications Of Digital Twin

The adoption of this technology is rapid due to its high flexibility. A better data-driven analysis can be made to improve patient care through DT. According to the Vice Chairman of the IBA Data Law Subcommittee, Laura Ziferman, DT collects a large volume of real-time data, mostly personal and confidential, and is prone to hacking and cybersecurity breaches. Effective data governance mechanisms to manage and control the exchange of data are to be ensured by DT users, especially organizations. Organizations must build trust when using DT technology by providing advanced protection and security systems. It is also essential to address issues of ownership while using.

DT as it is not protected. DTs are modelled after a physical object and may also be associated with intellectual property (IP), such as designs and patents; the digital twin could be subject to restrictions on the use of such IP. Organizations should include liability clauses in their contracts and obtain insurance coverage to mitigate such risks. Awareness levels vary widely across organizations regarding the risks associated with DT.

A comprehensive knowledge and understanding of risk management is highly required among all organizations [10]. Despite this, the State should introduce strong legislation to protect its users as new technologies enter the market. As DT is growing and gaining its popularity, organizations should consider: 1) cybersecurity, 2) modelling risk, 3) intellectual property, and the allocation of risk.

4.1 Cybersecurity

Security networks and encryption must comply with laws and regulations when handling sensitive personal data and its storage.

4.2 Modelling Risk

There should also be careful consideration of who will be able to access various branches of the data and for what purpose, and the duration of the same, including any good-faith exclusions.

4.3 Intellectual Property

There should be consideration as to whether DT will contain copyrighted information that needs to be licensed with a sufficient life for the project or build.

4.4 Allocation of Risk

As mentioned earlier, ownership and licensing had effects on liability, including companies and individuals contributing to data input, and for those [11].

5 Medical Liability

In relation to liability, DT raises very specific questions, such as:

5.1 Maintaining Sacred Relationship Between Doctor and Patient

Cyber-connected patients play a leading role in their own health, or play an expert role in their pathologies, to the point where he sometimes questions the diagnosis and therapeutic solutions proposed by the doctor, which creates difficulty in maintaining a good relationship between doctor and patient, where human contact is one of the fundamental aspects of personal care. The French legislator is proposing to establish in law a principle of ‘human guarantee’, in order to guarantee human supervision of any use of digital technology in healthcare.

5.2 Role of the Decision Maker is in Question

To avoid the doctor becoming a mere executor of the machine's prescriptions, it is crucial to sanctify the doctor's decision-making role [12].

5.3 Medical Malpractice

In medical malpractice, Health Digital Twins (HDTs) could gain prominence in proceedings as legal tools. Parties could legally vindicate or incriminate medical professionals after treatment based on prior collected health data.

5.4 Informed Consent

For a successful informed consent following grounds must be proved: (1) lack of proper disclosure of performed treatment or alternative treatments to the patient; (2) lack of information leads to patients denial of receiving the performed treatment ; (3) injuries suffered by the patient; (4) the treatment, was a substantial factor for the cause of injuries in patient; and (5) compensable damages for injuries in patient [13].

In order to find out the paucity and possibilities in enforcement measures and conclude with the insights for strengthening the robust institutional framework with an effective regulatory mechanism for the application of the DT. The study primarily followed the analytical method; however, to measure the operational extent of the digital platforms in the healthcare sector in India in comparison to other jurisdictions, a meta-analysis is quintessential, as the application of DT technology relies on the strength of digital infrastructure. Hence, the empirical study has also been adopted.

6 Integration Of Digital Twin And Spaces Of Exploitation In Indian Healthcare Sector

The pandemic raised awareness regarding digital tools and technologies that capture patient records and are available to patients. However, India is still very low in maintaining health records digitally. In the future, telehealth will raise the effectiveness of healthcare expenditure in India, which is largely rural. To create a health blueprint and unified health interface in healthcare, gradual progress is made. Universal Health Interface, Urban Health Initiatives (UHI), is going to join the larger population of India, the rural population, to various health services which can be available remotely and digitally, and that will create more digital data in the hands of the patients, who can then choose with whom to share that data in the future for personalized and precision medicine. The Indian health system can directly implement health and wellness measures with the right kind of technology accelerators, which are based on a digital twin model. The ultimate point of DT is to achieve improvement in care and health at an effective cost through technologies that can also enable remote adoption and delivery, thereby

addressing the challenges related to technology involvement at large in the Indian healthcare sector [14].

Recently, the Government of India started taking initiatives with the Department of Telecommunications (DoT), conducted at IIIT Bengaluru, 'Sangam: Digital Twin', which will help India move forward towards becoming the most developed country by 2047. According to Telecom Secretary of IIIT Bengaluru, Dr Neeraj Mittal, the initiative stemmed from Prime Minister Narendra Modi's call for futuristic infrastructure. A reshaping of infrastructure, planning, design, and next-generation computational technologies will be offered by the initiative. To develop India into a new era of digital empowerment and technological advancement, the 'Sangam: Digital Twin' initiative is one of a kind. It will strengthen unified data and collective intelligence, and also assist in the formulation of sustainable infrastructure, scalable development of development projects in the future. It offers a solution by creating virtual replicas of physical assets, allowing for real-time monitoring, simulation, and analysis for experimental iterations and a feedback loop to adapt to the changes for achieving the best outcomes. The global movements towards smart infrastructure positioned India at the forefront in digital infrastructure and innovation [15]. In the US, digital twins are developed by medical centers for the improvement of surgical outcomes for patients' kidneys and also to provide advanced training for surgeons. Similarly, in India, healthcare companies have started utilizing this technology to build heart models for patients. Virtual patient models personalized treatments, like precise diagnosis and treatment planning, are now possible. DT also helps surgeons to improve skills and minimize errors.

DT has emerged three main types of purpose and scope: 1) to make analysis, predict, and optimize the daily performance of individual components digital counterparts are utilized, 2) a predictive analysis is offered on how components interact and perform together, and 3) DT are intricately model specific segments which provide highly detailed virtual representations that plays, main role in optimizing processes, increasing productivity, reducing defects, and ultimately adding significant value to operations.

While there are numerous benefits of DT and it is still growing its wings towards ultimate development in various sectors, there are still several challenges to successful implementation. For widespread adoption of DT in the healthcare sector in India addressing challenges comprehensively is crucial: 1) infrastructure and connectivity need to be upgraded and enhanced in particular to rural areas, as slow internet access can hinder real-time data exchange, 2) security and regulatory compliance also face hurdles, due to the rise in cyber threats, 3) interoperability and standardization across manufacturers is critical for adoption and success of DT solutions, 4) the shortage of skilled professionals in data analytics, simulation modeling, social awareness and cybersecurity emphasized upon the importance of aligning educational programs with market demands, 5) substantial upfront costs could be an obstacle for small and medium-sized enterprises (SMEs) [16].

In short the opportunities of DT in healthcare sector are as follows: 1) to get personalized and precision medicine for each patient, 2) risk reduction in surgeries through planning and virtual replicas, 3) remote monitoring and disease management can be easily possible through DT, 4) healthcare operation at its optimal through drug development and virtual clinical trials which accelerate development process as well as cost reduction, and 5) strong growth in India's healthcare market.

7 Opportunities & Challenges Of Digital Twin In Indian Healthcare Sectors

The developed tech-sovereign countries of the northern hemisphere of the globe have already integrated state-of-the-art digital technologies to enhance efficiency, interdisciplinary networking, flexibility, responsiveness, and potential future research explorations in various sectors.

It mainly focuses on accessibility, reliability, availability, affordability, connectivity, predictability, and safety to flourish. Digitalization brings multiple benefits in the global digital economy, such as closing the global digital divide, building a digitally skilled workforce, and developing secure, reliable digital systems. In 2023 (one of the continuing pandemic years), about one-third of the global population, or 2.6 billion people, remained offline, where the high-income countries' internet usage is 90% in 2022; only used the internet. With the rapid popularity of digitalization, the most common question that comes with it is its safety. Data protection and cybersecurity laws play a crucial role in bringing a reliable answer to it [17].

Healthcare technologies such as mHealth, health informatics, and telehealth have developed to bring faster, more efficient, and cost-reducing practices. It has also been predicted that telemedicine and telehealth will gain more popularity in the near future [18]. With the introduction of many digital healthcare technologies, Digital Twin (DT) Technologies are the most recent development in the healthcare sector. It is the seamless integration of data from different platforms of digital technologies through interoperability and replicating the designated real-time physical object of the data sources for the purpose of creating the virtual model, that is, non-living physical entities. To create this prototype, a cohesive system composed of hardware, data management middleware, and software is required for monitoring, maintenance, and integration of that data.

Challenges with the development of DT are: 1) data privacy and security are still in question, 2) lack of standard operative procedures, 3) lack of regulatory and ethical ambiguities, 4) lack of skilled-based personnel, and health inequity, socio-economic inequity towards remote rural populations and underserved communities.

8 Conclusion

DT in India is at an early stage of being incorporated in various crucial sectors, such as the healthcare sector. However, with the technological advancements that recently spiked up after the pandemic, it is certain that within a couple of years, DT is going to play an important role not only in the healthcare sector but also in other sectors as well. It will benefit patients and healthcare providers immensely if proper data security and protection are available to users. By introducing pilot projects in high-impact zones, developing interdisciplinary talent, and implementing robust regulations and standards, India can realize the full potential of DT.

9 Recommendations

Implementation of ethical, legal, and regulatory frameworks is required to fully launch DT in healthcare, such as: 1) to introduce social awareness programs including digital literacy in remote areas, 2) to make cross-disciplinary training programs to bridge the digital technology gaps, and 3) to extend twin capabilities in rural areas and underserved communities. Low-cost platforms are required

Authors' Contributions

Conceptualization and Design of the Study: Author 1 contributed the initial research idea and theoretical framing, and Author 2 refined the conceptual framework and methodological approach.

Review & Supervision: Author 2 provided overall research oversight, academic direction, and oversaw the final revisions.

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